Soil Bioengineering

General

Soil bioengineering is the use of plant material, living or dead, to alleviate environmental problems such as shallow rapid landslides, and eroding slopes and streambanks. In bioengineering systems, plants are an important structural component, not just an aesthetic component. This approach to slope stabilization requires a true partnership between engineering geologists, maintenance personnel, civil engineers, and landscape architects.

Soil bioengineering technology has been practiced for thousands of years. Chinese historians, for example, recorded the use of soil bioengineering techniques for dike repair as early as 28 BC. Construction of the German autobahn system during the 1930s involved extensive applications of soil bioengineering technologies.

Soil bioengineering most often mimics nature by using locally available materials and a minimum of heavy equipment, and can offer roadside managers an inexpensive way to resolve local environmental problems. These techniques can also be used in combination with "hard" engineering techniques such as rock or concrete structures.

Soil bioengineering project areas require periodic monitoring and maintenance until plants have become established.

Benefits of soil bioengineering include:

- Erosion areas often begin small and eventually expand to a size requiring costly traditional engineering solutions. Installation of soil bioengineered systems while problems are small will provide economic savings and minimize potential impacts to the road and adjoining areas.
- Soil bioengineering work is often the only practical alternative on sensitive or steep sites where heavy machinery is not feasible.
- Many designs can be implemented by hand crews.
- Native plant species are usually readily available and adapted to local climate and soil conditions. Costs might be limited to labor for harvesting, handling, and transport to the project site.
- Soil bioengineering projects may be installed during the dormant season of late fall, winter, and early spring. This is the best time to install plants and it often coincides with a time when other construction work is slow.

- Years of monitoring have demonstrated that soil bioengineering systems provide limited initial benefits, but grow stronger with time as vegetation becomes established. Even if plants die, roots and surface organic litter continue to play an important role during reestablishment of other plants.
- Once plants are established, root systems remove excess moisture from the soil profile. This often is the key to long-term soil stability.
- Soil bioengineering provides improved environmental functions, such as slope stabilization, stormwater retention, and habitat values.

References

Design Manual (M 22-01), Soil Bioengineering Chapter.

USDA Natural Resource Conservation Service. Chapter 16, "Streambank and Shoreline Protection," *Engineering Field Handbook*. United States Department of Agriculture, 1996.

USDA Natural Resource Conservation Service. Chapter 18, "Soil Bioengineering for Upland Slope Protection and Erosion Reduction," *Engineering Field Handbook*. United States Department of Agriculture, 1992.

H.H. Allen and J.R. Leech. *Bioengineering for Streambank Erosion Control - Report 1, Guidelines.* Technical Report EL-97-8. U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS. 1997. Can be found on the Internet through the following link: http://www.wes.army.mil/el/wetlands/wlpubs.html

Resources

The region's Materials Engineer

Olympia Service Center (OSC) Roadside and Site Development Unit

OSC Materials Lab, Geotechnical Branch, Engineering Geologists and Geotechnical Engineers

The region's Landscape Architect

State Horticulturist

Definitions

angle of repose the angle between the horizontal and the maximum slope that a soil assumes through natural processes.[1]

Approximate Angle of Repose for Soil Texture	
Very wet clay and silt	1V:3H
Wet clay and silt	1V:2H
Dry sand and gravel	1V:1¾
Dry clay	1V:1½
Moist sand	1V:1¼

slope gradient the angle of the slope as expressed in a percentage.

soil bioengineering the use of live plant materials and engineering techniques to reinforce soil and stabilize slopes.

Planning

Evaluate soil bioengineering methods as a possible tool for remediation and restoration of degraded slopes. Soil bioengineering has unique attributes, but is not appropriate for all sites. In some cases a conventional vegetative treatment works with less cost, or it may be best to use a geotechnically-engineered system alone or in combination with soil bioengineering.

- Evaluate projects that leave exposed slopes, and slopes requiring high maintenance for stabilization, for possible application of soil bioengineering technologies.
- Include bioengineering technologies as an alternative when evaluating costs.
- Include a slope stability analysis in plans for large erosional slopes.

Design

Landscape Setting and Uses

Consider the natural history and evolution as well as cultural and social uses of the surrounding landscape. An awareness of these factors, and how they shape the present and potential future landscape, is critical for project success.

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[1] Robert W. Zolomij. "Vehicular Circulation." *Handbook of Landscape Architecture Construction.* 1975. p. 66.

Knowledge of current and future roadside and land management goals is essential for project success. Consider the natural history, cultural, and social issues of the surrounding landscape as well. A proposed soil bioengineering project within a forested landscape, for example, requires knowledge and understanding of:

- Road construction methods and current maintenance practices.
- Objective of the bioengineering project - repair, remediation, prevention, habitat, etc.
- The area's geologic and glacial history.
- Its propensity for wild fires, wind storms, and floods.
- Occurrence and trends of natural and management related erosion.
- Sequence of vegetation removal and revegetation efforts.
- Fire management history.
- Soil Types and Properties
- Hydraulic and hydrological erosion and scour characteristics.

Trends Within Erosion Sites

Whether erosion occurs naturally or through human-induced activities, a site begins to heal itself immediately upon “failure” by trying to achieve an angle of repose. In mountainous terrain, for example, wood may become embedded in the slope thus terracing eroding soils. Once an angle of repose has been achieved between these natural terraces, vegetation begins to establish. Herbaceous plants usually provide initial vegetative cover on these sites. This initial cover also assists in establishment of soil microorganisms. Typical succession patterns evolve in stages from exposed ground, through herbaceous plant, shrub, pioneer tree, and finally mature tree stages. The first step is to examine and document these trends. Soil bioengineering designs are used to accelerate site recovery by mimicking what is happening naturally.

Site Evaluation and Design Check List

There are many soil bioengineering systems. Selection of the appropriate technique, or techniques, is critical to successful restoration. At a minimum, consider the following:

Climatic Conditions:
Climates near the ground can vary considerably within short distances. South facing valley walls, for example, receive more direct sun rays,

which cause higher soil temperatures, increased evaporation, more rapid snowmelt in the spring, and generally drier conditions than on the more shaded north facing walls. This difference will influence erosion rates and the composition and vigor of revegetation efforts.		
		Precipitation types, amounts, seasonal variation, and duration.
		Temperatures, including seasonal averages and extremes.
Topography and Aspect:		
		Slope gradient.
		Terrain shape (for example, gentle slope to valley or sharp peaks).
		Elevation of project area.
		Direction of sun exposure.

Soils		
Identify conditions above, below, or within the project site that might have an effect on the project and incorporate these considerations into the design. Consult with the OSC Engineering Geologist to determine need for slope stability analysis. Some categories below will require soil testing to determine.		
		Substrate - take soil probe sample from potential site.
		Soil types
		Soil permeability
		Moisture holding capacity
		Nutrient availability

Water Detailed analysis or work in streams or rivers will require consultation with an hydraulics engineer. Work affecting streams or rivers will require consultation with the regional environmental office.		
		Water velocity: Lateral stream stability
		Hydrologic regime: general and site

		specific.
		If applicable, stream and fish types affected by the erosion site.
		Location of natural drainage channels and areas of overland flow from road surfaces.
		Areas for safe water diversion.
		Condition of ditch line and culvert inlets and outlets.
Erosion Process		
		Evidence of past sliding: deep or shallow failure surface in vicinity.
		Regional geomorphic trends or slope features (review aerial photos).
		Type of mass wasting or surface erosion feature.
		Source of eroding material: road fill slope, cut slope, landing, etc.
		Trend of site: improving naturally, remaining uniform, or worsening.

Vegetation		
		Plant species and amount growing within and adjacent to project site. It is especially important to identify colonizing species.
		Locations for plant and seed collection.

Plant Materials

Living vegetation is the most critical component of a bioengineered system. Existing vegetation and knowledge of predisturbance plant communities can inform the designer of project limitations, opportunities, and long-term ecological goals.

Work with local native plant experts, the State Horticulturist or the region's Landscape Architect, to select the most appropriate plant species for the project area.

Deciding which plants to use is affected by the following factors:

- Site characteristics (topography, elevation, aspect, soil moisture, nutrient levels).
- Existing vegetation.
- Intended role of vegetation in the project.
- Growth characteristics and ecological relationships of the plants.
- Availability.
- Logistical and economic constraints.

Plants that can resist mechanical stresses of erosion, floods, and landslides, while developing a strong, stabilizing root system are best suited for soil bioengineering applications.

Figure 740.1 Willow Rooting After 6 Week Immersion in Water.

Examples of riparian plants suitable for soil bioengineering work include willow, dogwood, cottonwood, big leaf maple, spruce, cedar, aspen, and alder.

Plants better suited for drier and poorer soil conditions include bitter brush, basin big sage, rubber rabbit brush, snowberry, white pine, lodgepole pine, Douglas maple, oceanspray, and blue elderberry.

The best indicator of which plant materials to consider for the soil bioengineering project are the plants growing on or adjacent to the project site.

Plant materials are chosen from among those species available on the site or nearby. Alternatively, it might be possible to salvage like species from a similar area where vegetation is scheduled to be removed. Logistical concerns are important in the selection of plant material.

A single species may serve the primary structural requirement of the vegetation in a soil bioengineered system. However, it is preferable to use a mixture of species with varying but complementary characteristics. Benefits of using multiple species include:

- Lower susceptibility to devastation by disease or pests.
- Combinations of deep and shallow rooting species and vegetation of varying heights.
- The system is allowed to respond to changes in site conditions.

Construction

Project Planning and Implementation

Coordination & Communication

- Develop and implement a communication plan to keep all players involved, interested, and informed.
- Establish clear project objectives. Have these objectives reviewed and approved by participants including the maintenance personnel and the region's Landscape Architect.
- List all project phases. Under each phase, catalogue and schedule all work items. For each work item, list the responsible parties and the dates the tasks must be completed. Identify and resolve timing conflicts. Build flexibility into the schedule (the Work Breakdown Structure).
- Ensure coordination between heavy equipment operators and hand crews.

Site Work

- Sites often require earthwork before installing a soil bioengineering system. Resolve timing conflicts that occur between scheduling heavy equipment, hand labor work, plant collection, and use.
- Select the right equipment for the job.
- Identify and remove work hazards.
- Determine access route for people and machinery to minimize site disturbance. For example, limiting hand crews to one entrance and exit route will cause less soil disturbance to the site and adjoining areas.
- Temporarily divert excess water.
- Stockpile excavated soils. Place soil in windrows to allow soil organisms access to oxygen. The least amount of time the soil is stockpiled the better.
- Retain or salvage existing vegetation for later use. Salvage material from healthy, young plants.
- Provide temporary surface erosion and sediment control measures.

Project Work

- Before beginning a project, conduct an on-site meeting. At a minimum, include team members with vegetation, local climate, and soils knowledge.
- Avoid earthwork in saturated soils. When possible, schedule heavy equipment work during periods of low precipitation.
- Round the top edge of a slope failure, which is often a vertical face. For project success, it is critical to address this “initiation point” or persistent source of erosion by removing or rounding off the slope overhang.
- Smooth all eroding areas such as rills or gullies. In addition, prepare a seed bed by slightly roughening the area. Do this by raking across the slope face, not downhill.
- Create terraces when slopes exceed 35 percent. Dig these terraces 250 to 350 mm (10 to 14 inches) deep across the slope face. Horizontal spacing usually varies from 1.2 to 3 m (4 to 10 feet) depending on conditions. The objective is to accelerate establishment of plants by reducing the slope angle of the planted locations.

Inspect project work daily.

Transplant Guidelines

The reason for setting transplant guidelines is to increase the likelihood of plants surviving, growing to maturity, and reproducing. The chance of success is much greater if plants from the same altitude and ecosystem are used because they are adapted to that area's climate and elevation.

Collect plant materials during the dormant season. Keep them protected from wind and heat. Best results are obtained when installation occurs the same day materials are collected. However, some believe greater success can be realized with cuttings if stems are soaked in water 5 days prior to planting. Protecting stems from wind and keeping them cool and moist is essential.

Upland Plant Species

Use local seed (collection) zones to identify the best areas to collect seeds, cuttings, or plants. A seed zone is an area with a defined boundary and altitudinal limits within which landform and climate are sufficiently uniform. The State Horticulturist or Botanist will be the source of information.

In 1966, seed zones were developed, based on climatic and physiographic information, to reduce the risk of maladapting commercial tree species and to provide structure for commercial seed trade. Each zone has geographic boundaries and is additionally divided into 150 m (500-foot) elevation intervals. Seed lots are coded by both seed zone and elevation band.

- When collecting seeds, cuttings, or plants for smaller projects (perhaps a one-time collection) the elevation band can extend approximately 75 m (250 feet) above and below the site.
- Salvage and transplant while plants are dormant.
- Collect cuttings from 30 to 50 parent plants in good condition (if available). In general, take no more than 33 percent of the parent plant's material and take no more than 50 percent of cuttings or seed from a given area.
- For plant cuttings, use young shoots (1 to 2 years old). Older and larger stems tend to have higher mortality.
- Protect cuttings from wind by covering them with plastic sheeting or moist cloth.

Shrubs, Forbs, Grasses, and Riparian Species

Use watershed boundaries as seed, cutting, and plant collection and transplant zones. In addition, collect all plant material within a 150m (500-foot) elevation band of the planting site.

Gene Pool Conservation Guidelines

Making sure the seed lot, cuttings, or plant lots are genetically diverse is just as important as plant movement guidelines. To prevent loss of genes in the population, use a minimum of 30-50 unrelated donor plants. Collecting an equal number of seeds, cuttings, or plants from each donor plant or area will also ensure representation by as many parent plants as possible.

Separate donor plants by sufficient distance to the reduce risk of relatedness.

Planting

- Plant salvaged plants within about 2 hours of lifting. Keep plants moist and free from wind and heat exposure.
- Dig holes 2 times the volume of the root ball. Larger holes will be required in more compacted soils.
- Planting holes must be deep enough so that the downslope side of the rootball is entirely buried.
- Plant the plant so the root collar is at the depth at which it was previously growing.
- Spread roots out so none are kinked or circling. Protect roots, especially fine root hairs on the main root system. Add water, if available, to reduce voids and increase root and soil contact.
- Use on-site soil to backfill the hole. Firmly tamp the soil around the plant. Be careful not to compact the soil.
- Transplanting a microsite: Depending on site conditions and project objectives, it might be preferable to salvage and transplant a small section of ground. This section usually contains several plants with roots, mycorrhizae, seed, soil, soil microorganisms, and duff materials. This technique provides great benefits to the area being revegetated. For transplanting small sections of ground, excavate an area large enough to “plant” the entire piece. Lay it in the excavated area and level with adjoining ground. Use excavated soil to secure edges of transplanted piece. Tap gently into place. Whenever possible, water the transplant.

Seed, Fertilizer, and Mulch

Figure 740.2 Hand-Distribution of Mulch

Broadcast or hydroseed seed, fertilizer, and mulch. Make sure seed is covered with the correct depth of soil. The depth will depend on the type of seed being used. Check with the State Horticulturist for correct planting depths for the seed mix. Decomposed organic amendments, in place of fertilizer, also work well.

It is necessary to protect the site from additional surface waterflow, specifically overland flow from roads. Direct the water flow away from the project area with gravel drains, swales, culverts, or drainpipe.

Weed-free straw or wood cellulose fiber mulches can be used as a mulch to minimize rain splash erosion. When using straw as a mulch, use as thin a layer as possible to cover the soil (less than 6mm [¼ inch]). Grass seed cannot sprout if the mulch is too thick.

Techniques

Details for installation of live facines, live staking, brush layering, brush mattress, live cribwalls, and live gabions can be found at: http://www.wsdot.wa.gov/eesc/cae/design/roadside/Bioeng.htm

Information on erosion control blankets can be found in Chapter 710, Erosion Control, of this manual and on the internet at: http://www.wsdot.wa.gov/eesc/environmental/WQTESC.htm

Live Staking

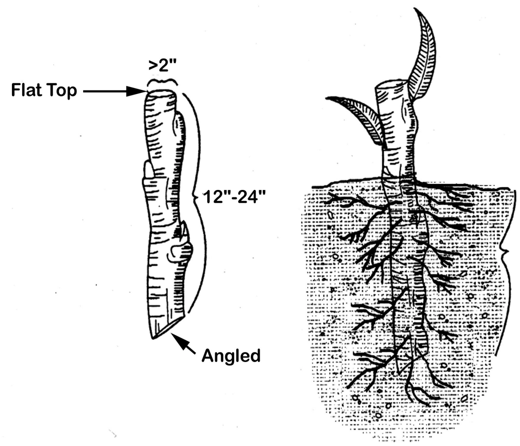

Figure 740.3 Live Staking

Live staking involves insertion and tamping of live, rootable vegetative cuttings (such as willow, cottonwood, and red-osier dogwood). If correctly prepared and placed during early spring, the live stakes will root and grow.

Advantages: A system of stakes creates a living root mat that stabilizes soil by reinforcing and binding soil particles together and by extracting excess soil moisture. This is an appropriate technique for repair of small earth slips and slumps that usually have moist soils.

Disadvantages: Does not solve existing erosion problems (excluding benefits from associated mulch). Staking is not a short-term solution for slope instabilities.

Erosion Control Blanket

Installation of erosion control blankets involves site preparation, trenching, application of grass, and/or forb seed mix and soil amendment, and installation of fabric. This technique is suitable for treating surface erosion areas, especially fill slopes where there is a concentration of surface water runoff. The erosion control blanket provides immediate protection of the soil from erosion. The seed mix will sprout, grow, and lock the underlying soil in place with its root mass.

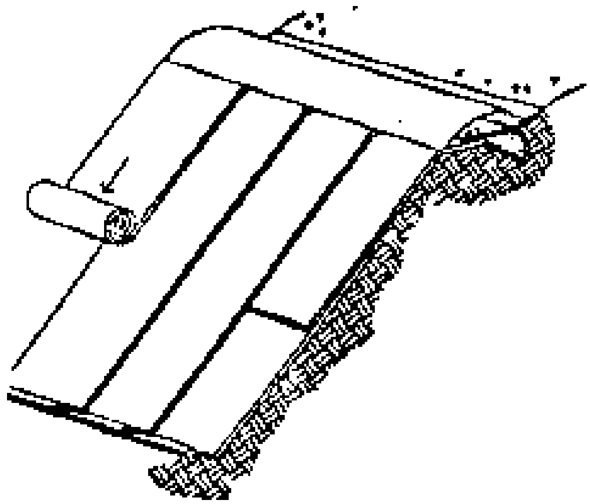

Figure 740.4 Erosion Control Blanket

Advantages: Excellent for mitigating surface erosion. The blanket offers immediate and uniform slope protection from rain and overland water flow.

Disadvantages: Can be labor-intensive and expensive. Could require numerous wood stakes or live stems to secure the erosion control blanket. Too much grass within the blanket will lead to over competition for moisture and high tree and shrub mortality if live stakes are used. If the seeding is too dense, the combined matting of these grasses with the blanket can prevent other grasses from emerging.

Live Cribwalls

Figure 740.5 Live Crib Wall Under Construction

A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material, such as topsoil, and layers of live branch cuttings, such as willow, which root inside the crib structure and extend into the slope. Tilt the cribwall back into the sloped surface at a 10% angle. Once live cuttings root and become established, subsequent vegetation gradually takes over the structural functions of wood members. Consider the flow of runoff adjacent to the wall to ensure that the wall will not be undermined. Contact the materials engineer for help in calculating slope stress.

Figure 740.6 Live Crib Wall with Willow Stakes

Advantages: Appropriate at the base of a cut or fill slope where a low wall, or log, might be required to stabilize the toe of a slope and reduce slope steepness. Useful where space is limited and a more vertical structure is required. Provides immediate protection from erosion and established vegetation provides long-term stability. Aesthetically more pleasing than gabion baskets.

Disadvantages: Not designed for or intended to resist large, lateral earth stresses. Depending on soil quality of cut slope, may have to use commercial fill material. Can be labor intensive and expensive to construct. Can have high mortality if willow stems are not collected when dormant, are not properly stored, or are mishandled in transfer.

Variation: Toe Log Technique

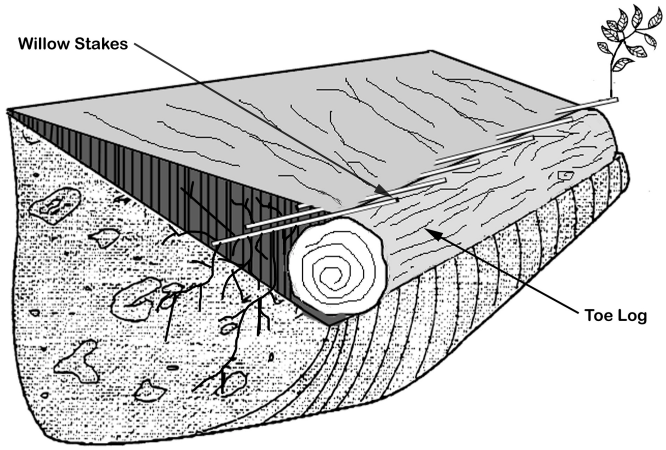

Figure 740.7 Toe Log Technique

This technique is handy for very small cut slope erosion features, for example, 3 m by 4.5 m (10 feet high by 15 feet) wide. Place a 500 mm to 635 mm (20 to 24 inch) diameter log along the base of the erosion site. Lay 1.75 m (5 feet) long and 12.5 mm to 38 mm (½ to 1½ inch) diameter trimmed, live branches on top of the log and sloping down into the cut bank. The purpose is to take full advantage of excess water at the slope base. Place soil behind the log with soils from the slope face. Toe logging is a quick and effective tool in stabilizing the base of slopes. However, the log must be outside the Design Clear Zone and the site must be small and only slightly over-steepened. It is very important to use the right size log for existing slope conditions. Contact the materials engineer for help in calculating slope stress.

As in any soil bioengineering technique, the initiation point or source of persistent erosion must be addressed. This is usually located at the upper boundary of the site. For project success, it is critical to remove or round off the slope overhang.

Live Fascines

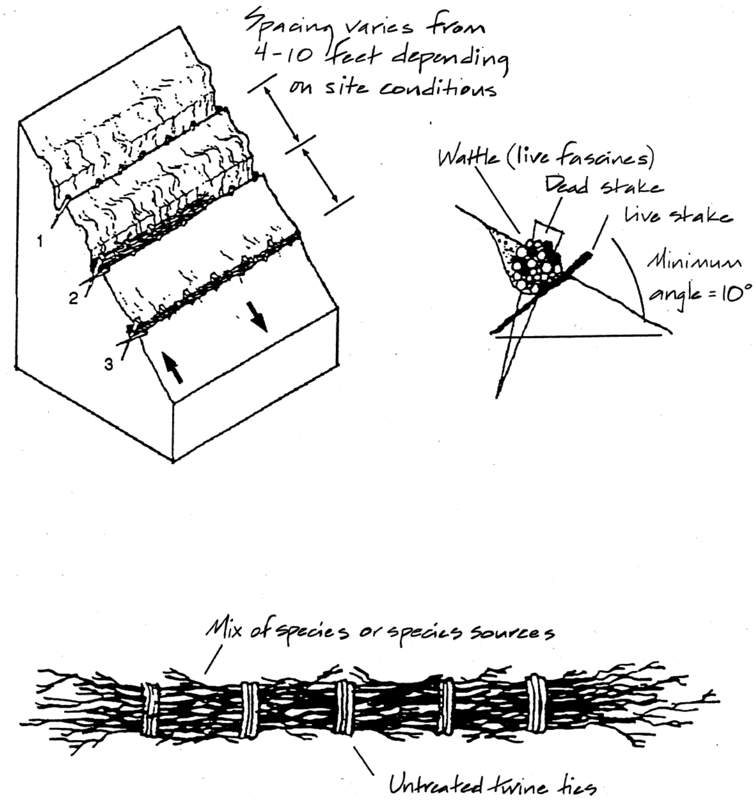

Figure 740.08 Live Fascines

Live fascines are also referred to as contour or willow wattling. They are long bundles of branch cuttings bound together into sausage-like structures that are placed in a trench parallel to the slope contour. Live fascines root into the slope face and provide a permanent structure.

Note: Where soil moisture is not sufficient to support live materials, fascines can also be constructed of plant stems not intended for rooting. The bundle still traps and holds sediments and reduces slope length and steepness between terraces. Plant vegetation between the terraces. As in all projects, recovery is dependent upon successfully establishing live vegetation.

Advantages: Immediately reduces surface erosion or rilling. Suited to steep, rocky slopes where digging is difficult. Capable of trapping and holding soil on the slope face, thus reducing a long slope into a series of shorter steps. Can also be used to manage mild gully erosion and can serve as slope drains when bundles are slightly angled. Best suited for moist soil conditions.

Disadvantages: On steep or long slope lengths, high runoff velocities can undermine fascines. A significant quantity of plant material is required and can dry out if not properly installed. Best suited for riparian, moist soil conditions. Otherwise high plant mortality could occur.

Brushlayering

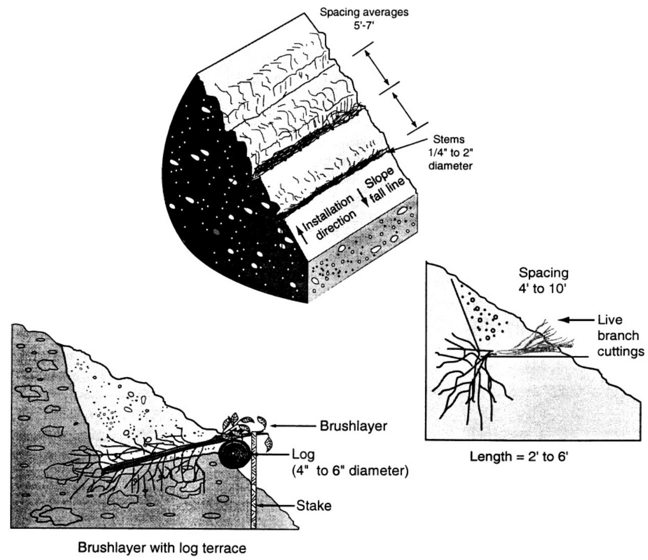

Figure 740.09 Brushlayering

Brushlayering consists of placing live branch cuttings in small terraces excavated into the slope. Terraces can range from 0.6 m to 1 m (2 to 3 feet) wide. This technique is similar to live fascine systems because both involve cutting and placing of live branch cuttings on slopes. The two techniques differ in the orientation of the branches and the depth at which they are placed on the slope. In brushlayering, cuttings are oriented perpendicular to the slope contour. This placement is more effective for soil reinforcement and stability of the slope.

Advantages: Breaks up slope length into a series of shorter slopes separated by rows of brushlayer. Reinforces soil as roots develop thus adding resistance to sliding or shear displacement. Reinforces soil with unrooted branch stems. Provides slope stability and allows vegetative cover to become established. Traps debris on slope. Moderates soil moisture by aiding infiltration on dry sites and drying excessively wet sites.

Disadvantages: Recommended on slopes up to 1V:2H in steepness and not to exceed 4.5 m (15 feet) in vertical height. Labor intensive.

Willow Fencing with Brushlayering

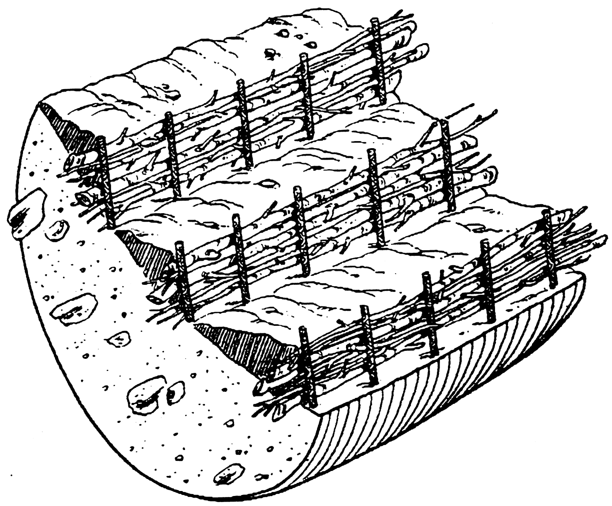

Figure 740.11 Willow fencing with brushlayer

Willow fencing with brushlayering is essentially a short willow fence supporting a brushlayer. Specifically, it is a short retaining wall built of living cuttings with a brushlayer at the base.

Sites where fine-textured soils can provide ample summer moisture, or where seepage of groundwater provides moisture, are suitable for willow/brushlayering fence installations.

These structures can also be constructed on drier sites. However, expect high willow mortality. In these situations, the willow/brushlayer shelf is considered a temporary planting platform. It is important, therefore, to establish deeper rooting shrubs and trees within the shelf.

When the structure begins to decay, root systems of the willows or the other plants will serve as the permanent feature.

Figure 740.10 Willow Fencing With Brushlayer

(brushlayer is hidden below soil from construction).

Advantages: These structures reduce slope angle, providing a stable platform in which vegetation can establish. Willow fences can help to trap rolling rocks and sliding debris and can protect vegetation growing lower on the slope. Willow fences provide support for small translational or rotational failures.

Disadvantages: Significant quantity of plant material is required. Moist site conditions are required for the fence to sprout and grow willows.

Figure 740.12 Leveling Line for the Next Willow Fence

Branchpacking

Branchpacking consists of alternating layers of live branch cuttings and compacted backfill to repair small localized slumps and holes.

Figure 740.13 Branch Packing in Winter

Advantages: As plant tops grow, branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills localized slumps or holes while roots spread throughout the backfill and surrounding earth to form a unified mass.

Disadvantage: Not effective in slump areas greater than 1.3 m (4 feet) deep or 1.6 m (5 feet) wide.

Live Gully Repair

Live gully repair uses alternating layers of live branch cuttings and compacted soil to repair small rills and gullies. Similar to branchpacking, this method is more appropriate for repair of rills and gullies.

Figure 740.14 Live Gully Repair

Advantages: Offers immediate reinforcement to compacted soil, reduces velocity of concentrated flow of water, and provides a filter to reduce rill and gully erosion.

Disadvantage: Limited to rills and gullies that are a maximum of 0.6 m (2 feet) wide, 0.3 m (1 foot) deep, and 5 m (15 feet) long.

Vegetated Geotextile

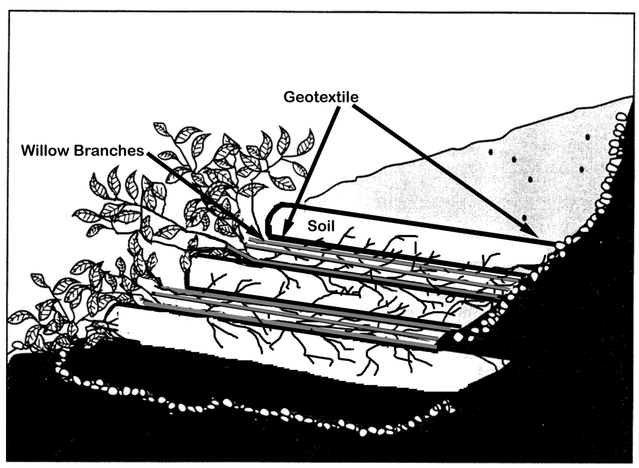

Figure 740.15 Vegetated Geotextile

This method uses synthetic or organic geotextile wrapped around lifts of soil with a mix of live branches placed between layers.

Note: Structural integrity is dependent upon compacted soil layers. Even with mechanized firming, soils support live cuttings.

Advantages: Retards rill and gully erosion and stabilizes fill banks. Is less expensive than other retaining walls such as gabion or Hilfiker baskets.

Disadvantages: Heavy equipment usually required to install lifts. Plants must be installed during their dormant season. Can be expensive.

Log Terracing

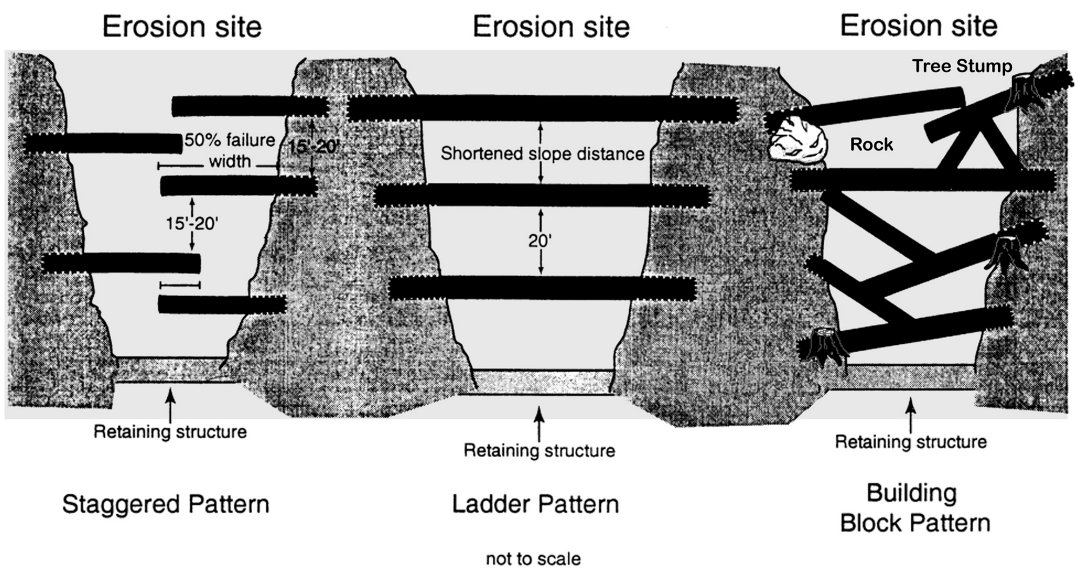

Figure 740.16 Three Toe Log Techniques

The log terracing technique uses alternating terraced logs to stop surface erosion on eroding slopes. Stopping the erosion is critical for successful revegetation efforts. Log terracing shortens the slope length and gradient between each structure, providing stable planting areas throughout most of the slope face. Logs must be installed in trenches and staked into place.

Note: Use logs that are a minimum of 0.3 m (12 inches) in diameter. Logs that are 400 mm to 500 mm (16 to 20 inch) in diameter work best. The most common error in log terracing is using logs that are too small in diameter.

Advantages: Logs create terraces reducing length and steepness of the slope. Provides stable areas for establishment of other vegetation such as trees and shrubs.

Disadvantages: Labor intensive and with possible safety hazards because of the use of logs on a slope. Heavy equipment required to place large logs.

Key Points:

- Involve all associated disciplines early in the process.
- Establish clear project objectives.
- Conduct predesign field review.
- Conduct plan-in-hand field review.
- Have a prework meeting with contractor to highlight key areas.
- Scheduling and timing of project is important when considering erosion outputs.
- When laying out the project, be consistent with the flagging.
- Ensure that terraces are level (on the contours) so that they do not act as stream channels. Level terraces will act to slow erosion.
- Diligent inspections of work-in-progress and timely feedback are critical. Develop a good working relationship with heavy equipment operators and hand crews. Poor inspection and poor communications can ruin a well designed project. Remember “You get what you inspect, not what you expect”!
- Monitor and document project effectiveness.
- Disseminate this information to colleagues and adjust future prescriptions based on monitoring results.
- Annual peer review by land managers provides good feedback and keeps them informed.

The complexity of the project dictates the level at which the aforementioned steps are performed.

An interdisciplinary team is necessary for all steps. The experience can also be very rewarding.

Maintenance

Maintenance crews can request assistance with erosional problems on slopes in their area. The region’s Materials Engineer and the region’s Landscape Architect, or the OSC Roadside and Site Development Unit for regions with no Landscape Architect, are available to help with the design and implementation of soil bioengineering measures to treat erosional slopes or shallow rapid landslides.

For the first one to two summers after construction, additional watering might be necessary. Thereafter, the vegetated system will usually require little or no maintenance and will usually cut down on ditch cleaning requirements because erosion has been minimized.

Additional Sources of Information

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